Princeton University

Design of a Modern Equipment General Aviation (MEGA) Aircraft

Flavio Poehlmann-Martins & Probal Mitra

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Advised by:

Prof. R. Stengel

Prof. L. Martinelli

Introduction

- Problem:
  - Declining popularity of general aviation
- Proposed Solution:
  - MEGA-plane
  - A 4-seat general aviation aircraft
  - Uses component redundancy and latest technology
  - Safer, simpler to fly, and more comfortable

Outline

- Specific problems with general aviation
- MEGA-plane specifications
- General design
- Inertia properties
- Flight control system:
  - Architecture
  - Reliability analysis
- Progress summary & future work

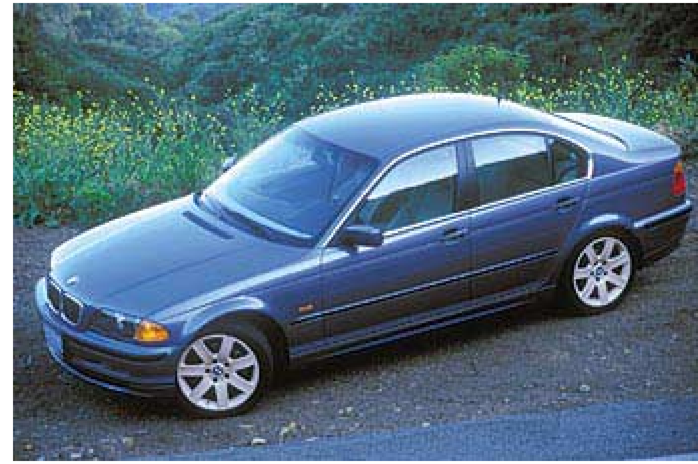
Problems in General Aviation

- Safety:
  - In 1997: GA accounted for 1,835 out of 1,975 aviation accidents (NTSB)
  - 31% of these accidents involved aircraft failure (NTSB)
  - 75% involved pilot error (NTSB)
- Comfort:
  - Typical GA planes: small cabin, lack of luggage space (e.g. Cessna Skyhawk)

Specifications

- Range: 1,000 nautical miles (1,151 miles)
- Cruise speed: 300 knots (Mach 0.5)
- Required takeoff field length: 2,000 ft
- Cruise altitude: 23,000 ft
- Thrust: 700 lbf
  (Williams Int.FJX-2 Turbofan)

Interior



- Passenger Cabin:
  - 4 passengers
  - Pressurized
  - Total volume: 105 ft^3
  - Dimensions:
    - Length: 6.7 ft
    - Width: 4.6 ft
    - Height: 3.4 ft
- Luggage Compartment:
  - Total volume: 18 ft^3
  - Dimensions:
    - Length: 2.6 ft
    - Width: 3.5 ft
    - Height: 2.0 ft

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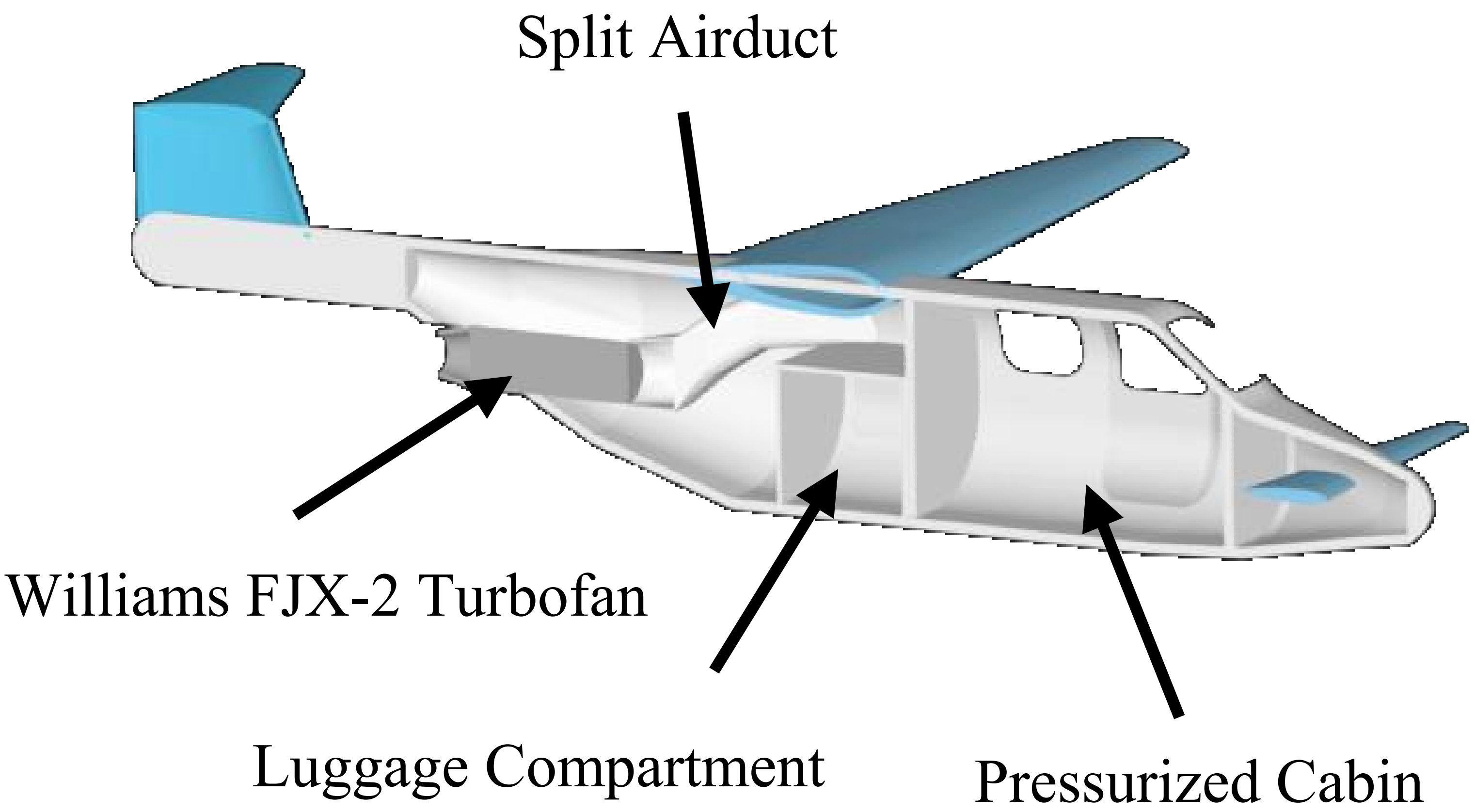
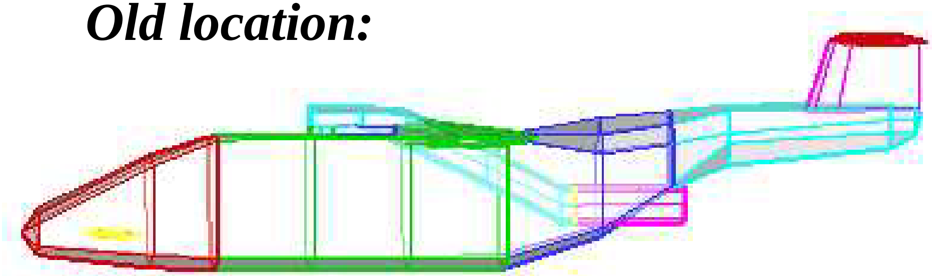
Design Overview

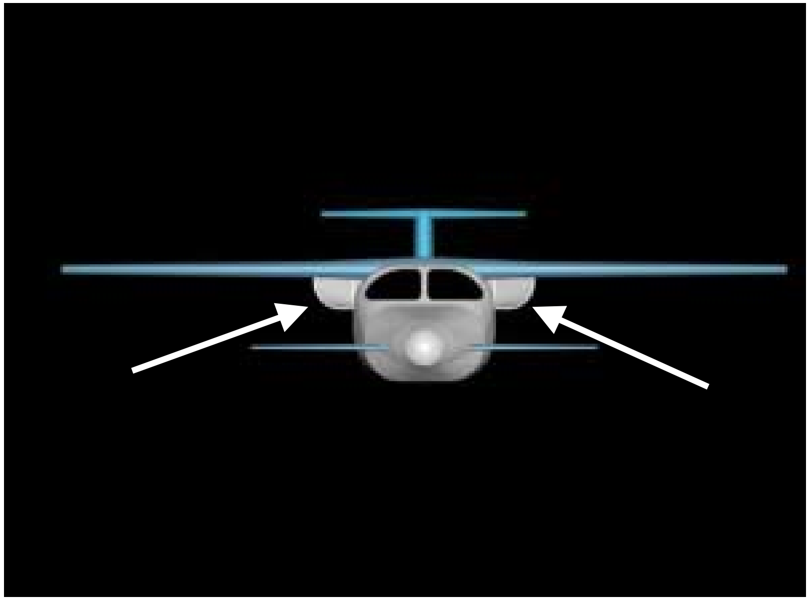


Airduct Location

Old location:



New location:



Advantages of new location:

- Shorter duct length
- Lower moments
- Redundancy (two inlets)
- Less risk at high angles of attack
- Structural support for wing
- Minimum risk of flow separation inside duct

Disadvantages:

- Increased drag (two inlets)
- Split duct (risk of engine stall)
- Stalled canard and wing-fuselage interaction may affect airduct inlet

Stability and Dynamic Performance Analysis

Goals:
- Determine stability (static and dynamic)
- Determine aircraft response to control surface actuation
- Combine these two to determine optimum aircraft geometry

Required Steps:
- Determine center of gravity location and inertia properties of aircraft

Software: Pro Engineer (Pro E)

- Perform aerodynamic analysis to get force and moment coefficients

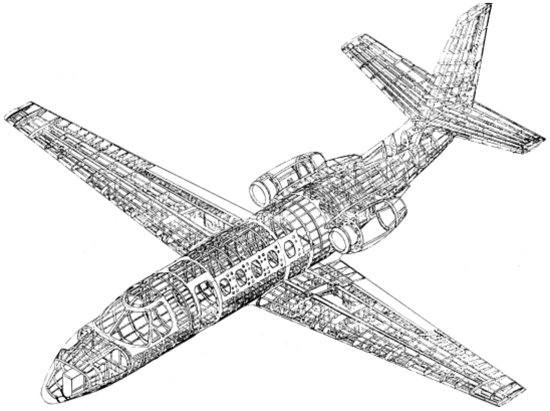
Software: Panair

Current Progress:
- Pro E model of plane created (needs refinement)
- Panair acquired

Mass Distribution Assumptions

Goal: Determine center of gravity and inertia properties

An Actual Aircraft:



•Basic load carrying shell reinforced by frames, longerons, spars, and ribs

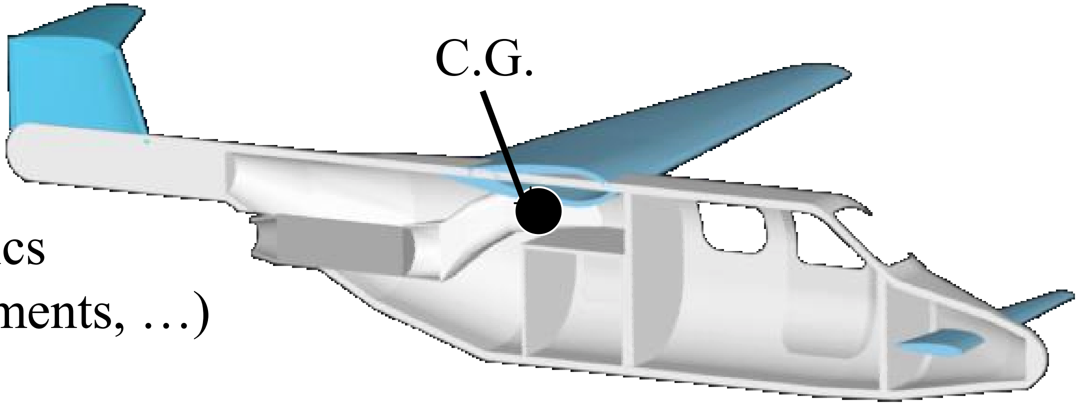
Model of the MEGA-Plane:

• Surface thickness modified to account for structural members
• Component weights obtained from geometry and statistics
• Densities assigned to components based on known weights and volume in model

Current Pro E Model

Components that remain to be added to model:

- Fuel tanks
- Retractable landing gear
- Avionics
- Auxiliary power unit
- Actuators and electromechanics
- Cockpit interior (seats, instruments, …)



Current Results:

	Current model of MEGA-Plane	Compare to Navion
Weight	719.9 lbs (will increase)	2,750 lbs
I_x	292.5 slug-ft^2	1,048 slug-ft^2
I_y	915.25 slug-ft^2	3,000 slug-ft^2
I_z	1,117.4 slug-ft^2	3,530 slug-ft^2

Typical Weight Breakdown of Similarly Sized Aircraft

- **Empty: 1,744 lb**
- **Passengers: 880 lb**
- **Luggage: 355 lb**
- **Fuel: 561 lb**
- **Takeoff: 3,540 lb**

Note: Numbers based on statistical information from existing GA aircraft

- Wing*: 149 lb
- Canard*: 45 lb
- Tail*: 19 lb
- Fuselage*: 326 lb
- Landing gear: 217 lb
- Engine & fuel sys: 259lb
- Avionics: 119 lb
- A/c & anti ice: 102 lb
- Flight Controls, hydraulics, and electricals: 228 lb
- Miscellaneous: 281 lb

*Composites

System Architecture & Redundancy Implementation

1. Decide on the target aircraft reliability:
   - 1997 GA accident and flight-time statistics show 10^{-5} failures/flight-hour
   - Complete system reliability goal: **10^{-6} failures/flight-hour**
2. Set up the architecture of a generic control-surface
3. Calculate the failure rates of individual components and hence for each flight control-surface from past data
4. Add redundancy to system configuration as needed to meet target.

Data Collection & Modeling

- Probabilistic Model:
  - Exponentially distributed component lifetimes, rate λ
  - Poisson distributed failures
  - Represent failure modes as continuous-time Markov chains (Osder)
- Source: Service Difficulty Reports (SDR)

  Submitted to FAA by pilots and technicians

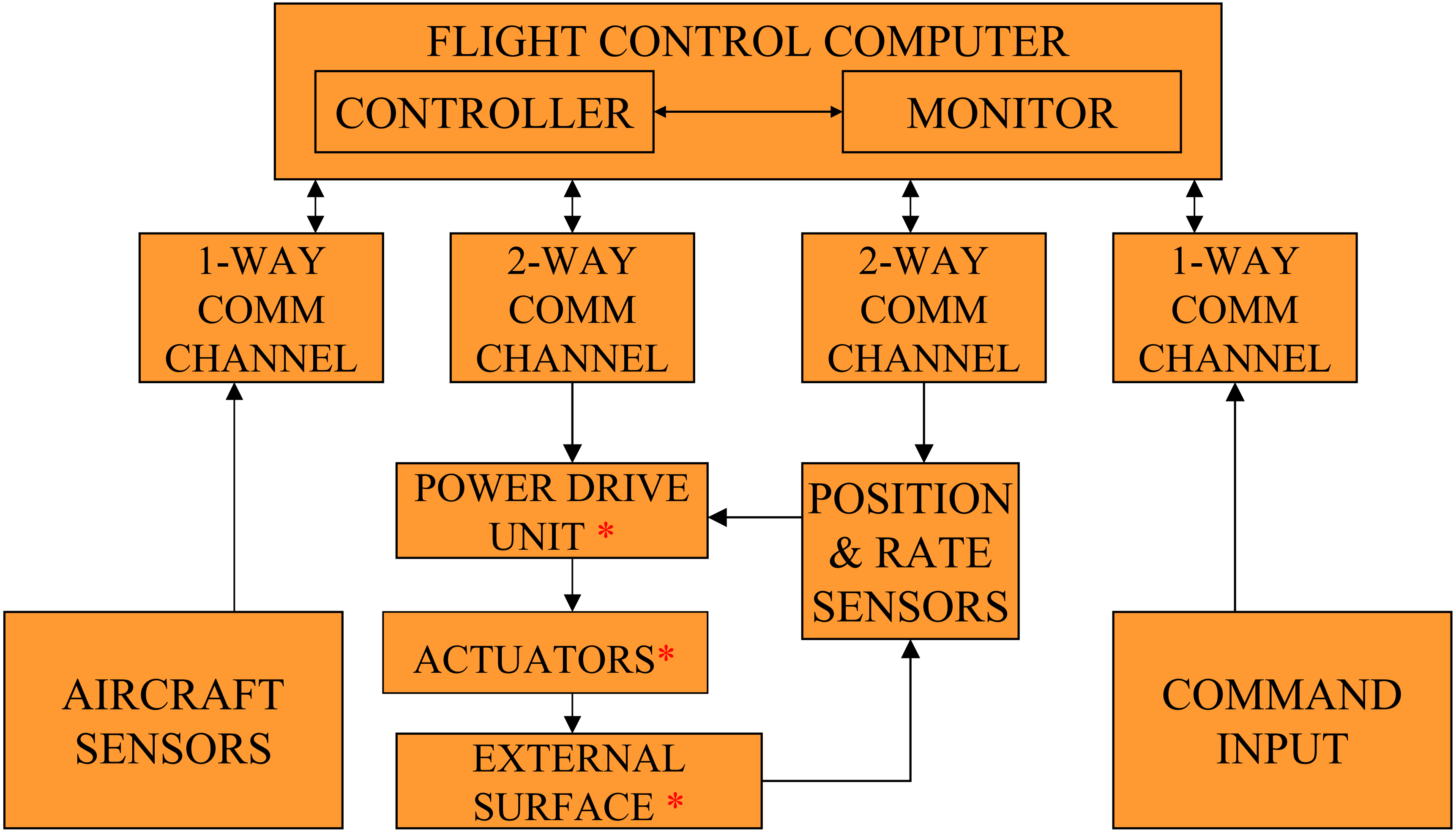
  Database: January 1995 – present (courtesy: Nelson Miller, FAA)

  http://av-info.faa.gov/isdr/SDRQueryControl.ASP?vB=NS&cD=32
- Calculate mean lifetime from service hours logged since component was last serviced
- Exponential failure rate L and mean lifetime T related by:

$$T = 1/ L$$

- Reliability rate R = 1 - L

Control Surface Architecture



Taxonomy of Parts

INTERNAL

- Electromechanical Devices:
  - Power Drive Unit (Motor)
  - Actuators (Gearing and Cables)
- Electronic Devices:
  - Flight Control Computer
  - Communication Channels
  - Pilot Input Data
  - Sensors

EXTERNAL

- Flight Control Surfaces:
  - Ailerons
  - Elevators
  - Flaps
  - Rudder

NOTE:

- "Flaperons" in final design
- Model flaps/ailerons separately
- Add required numbers for each to obtain flaperon total (increases redundancy)
- Adjacent ailerons for yaw

Reliability Data Results

(Excluding Electronic Components)

MEAN LIFETIMES

Flight Control Surfaces

- Ailerons: 5,743.4 hrs
- Elevators: 3,770.7 hrs
- Flaps: 5,521.4 hrs
- Rudder: 5,423.9 hrs

System Parts

- Motors: 3,054.3 hrs
- Actuators: 3,630.5 hrs

FAILURE RATES

Flight Control Surfaces

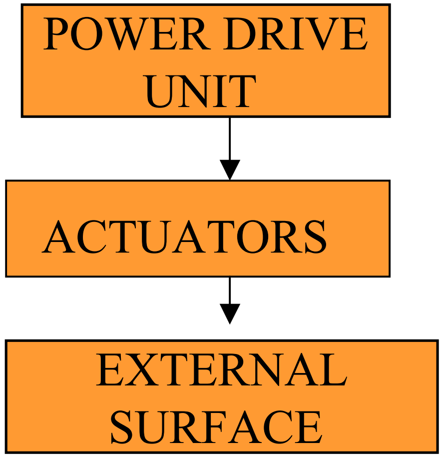
- Ailerons: $1.741\text{x}10^{-4}$/hr
- Elevators: $2.652\text{x}10^{-4}$/hr
- Flaps: $1.811\text{x}10^{-4}$/hr
- Rudder: $1.844\text{x}10^{-4}$/hr

System Parts

- Motors: $3.274\text{x}10^{-4}$/hr
- Actuators: $2.754\text{x}10^{-4}$/hr

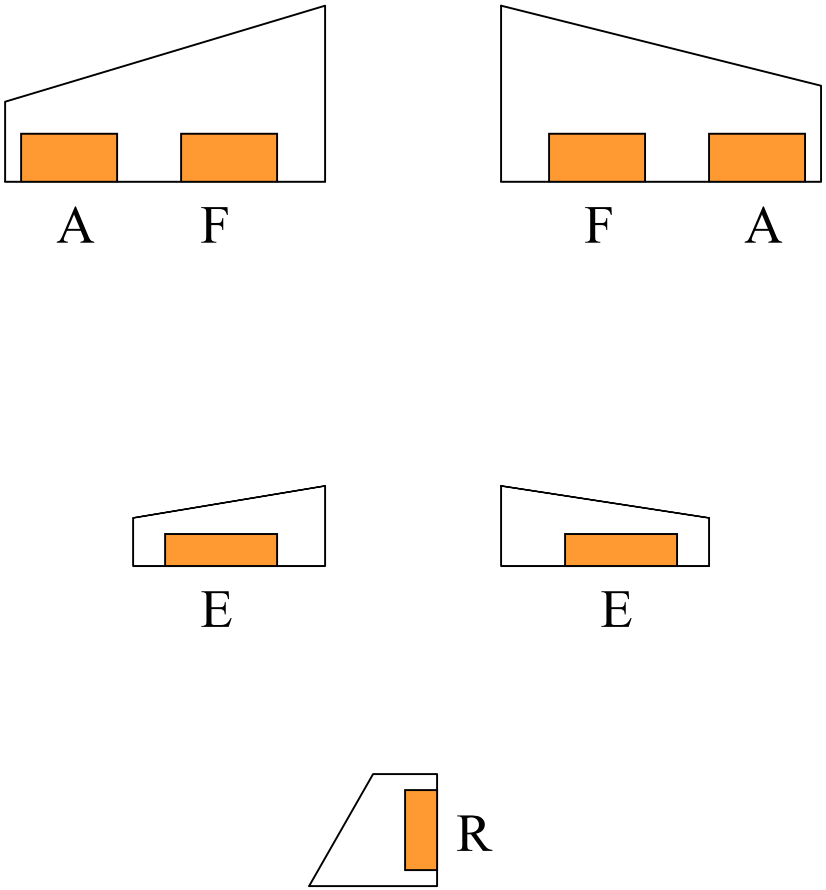
Sample Reliability Estimate (I)

- Assume:
  - Electronic components (control computer, communication channels, sensors) designed with negligible failure rates
  - Each control surface depends only on:
    - Power Drive Unit
    - Actuators
    - External Surface
- Complete control system failure rates λ :
  - Ailerons: 7.7677×10^{-4}/hr
  - Elevators: 8.6780×10^{-4}/hr
  - Flaps: 7.8376×10^{-4}/hr
  - Rudder: 7.8702×10^{-4}/hr



Sample Reliability Estimate (II)

- GA aircraft with no redundancy:
  - 2 Ailerons (T=1051.8hrs)
  - 2 Elevators (T=882.8hrs)
  - 2 Flaps (T=1036.6hrs)
  - 1 Rudder (T=1270.6hrs)
- Each component considered "vital" – reliabilities multiply in series (R = 1-1/T)
- Expected time between repair/maintenance: 261 flight-hours



NOTE:

- "Failure" means any single component malfunction (does not necessarily result in serious loss of control)
- Assumes no maintenance or servicing until a failure occurs

Progress Summary & Future Work

- Summary:
  - General design established
  - Mass model partially complete
  - Reliability data collected and analyzed for use in redundancy design
- Future Work:
  - Aircraft:
    - Refinement of mass model and exterior design
    - Aerodynamic force and moment coefficients (CFD)
  - Controls:
    - Finalize system configuration
    - Redundancy management laws

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